

NDVI-Based analysis on the influence of human activities on vegetation variation on Hainan Island

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Abstract. Using the Moderate Resolution Imaging Spectroradiometer-normalized difference vegetation index (NDVI) dataset, we analyzed the predicted NDVI values variation and the influence of human activities on vegetation on Hainan Island during 2001-2015. We investigated the roles of human activities in vegetation variation, particularly from 2002 when implemented the Grain-for-Green program on Hainan Island. The trend analysis, linear regression model and residual analysis were used to analyze the data. The results of the study showed that (1) The predicted vegetation on Hainan Island showed an general upward trend with a linear growth rate of 0.0025/10y ($p < 0.05$) over the past 15 years. The areas where vegetation increased accounted for 52.28%, while the areas where vegetation decreased accounted for 47.72%. (2) The residual NDVI values across the region significantly increased, with a growth rate of 0.023/10y. The vegetation increased across 35.95% of Hainan Island, while it decreased in 20.2% of the area as a result of human activities. (3) In general, human activities had played a positive role in the vegetation increase on Hainan Island, and the residual NDVI trend of this region showed positive outcomes for vegetation variation after implementing ecological engineering projects. However, it indicated a growing risk of vegetation degradation in the coastal region of Hainan Island as a result of rapid urbanization, land reclamation.

1. Introduction

Vegetation is the important part of ecological system, and is the most basic database using to describe the ecosystems. Acquiring the vegetation variable information is critical for understanding the vegetation variable and assessing the changes of global and regional ecological environment [1-4]. Vegetation index can reflect the vegetation growth. Hundreds of vegetation indices have been proposed, and the Normal Difference Vegetation Index (NDVI), which is recognized as the most commonly used remote sensing data in the characterization of vegetation change, is closely related to vegetation coverage, growth conditions, biomass and photosynthesis intensity, and with multiple dates of data, differences in NDVI can be help document changes in aspects of vegetation[5]. The MODIS NDVI data which was supplied by NASA for free had been widely applied in the evaluation of vegetation change and had been fundamental data for studying vegetation remote sensing in large scales [6-14]. Over the past 20 years, many domestic and foreign scholars had researched vegetation



variable and the effects of climate variable and human activities on vegetation in different regions to different extents. For example, Chen et al. researched the Xilingol vegetation change from 2000 to 2005 using MODIS NDVI [15]. Miao et al. acquired vegetation coverage during 2000-2007, and analyzed the cause of vegetation variable in Jilin province. Sun et al. analyzed the vegetation variation characteristics within North China using SPOT/NDVI, and distinguished the influence of climate variation and human activities[5]. It is clear that vegetation can be influenced both by climate variations and human activities. Due to the common effect of human activities, the ecosystem degradation and function disorders are becoming more and more outstanding, which restricts its ecological service function, and has brought serious harm to regional social economic development and ecological environment protection. Nevertheless, previous researches on the effects of climate and human activities on vegetation variable were primarily conducted in northern China, and sparse literature reports are available for southern China, little is known about how much vegetation variable is affected by climate and how much is affected human activities on Hainan Island. How extensive are the impacts of climate variations and human activities on vegetation change? The answer to these questions will play an important role in guiding the development of ecological construction on Hainan Island. This research used Moderate Resolution Imaging Spectroradiometer Normal Difference Vegetation Index (MODIS NDVI) data from 2001 to 2015 to assess the impacts of climate variation and human activities on vegetation variation on Hainan Island. We used statistical methods to redefine the roles of human activities in vegetation variation. In addition, we provide some theoretical evidence that demonstrated the benefits of ecological engineering projects and city expansion on vegetation variation on Hainan Island.

2. Materials and methods

2.1. Study area

Hainan island extends from 19°20'-20°10'N, and 108°21'-111°03'E (figure 1). The region, which is surrounded by the sea, is one of the native habitats for tropical rainforest and monsoon forest. Average annual temperature is between 22°C and 26°C, and precipitation varies greatly within and between years, decreasing gradually from east to west. Meanwhile, 70%–90% of the total precipitation falls from May to October, rainfall mainly occurs between August and September. Hainan Island plays an important role in the ecological security of China. The development of Hainan Island into an international tourist destination was part of a national strategy for development initiated in the early 2010s, extensive human activities including land reclamation, urbanization, tourist infrastructure construction and so on had resulted in serious vegetation variation.

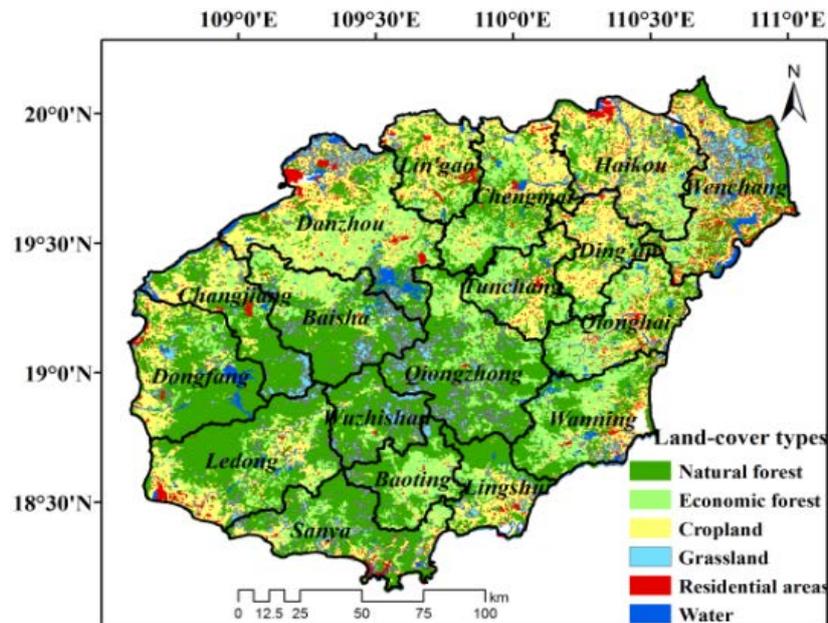


Figure 1.The study area.

2.2. Data sources

We obtained MODIS13Q1 NDVI data with spatial resolution of $250\text{m} \times 250\text{m}$ from EOS/MODIS product of NASA to analyze vegetation variation on Hainan Island from 2001 to 2015. The temporal resolution of the data was 16 days. Although the data had been dealt with water, clouds and heavy aerosol, to further remove the influence of clouds, we adopted the maximum value composite (MVC) to acquire annual NDVI data during 2001-2015. For this study area, two tiles of the MODIS NDVI product image (h28v06/h28v07) were selected. The NDVI data were re-projected from a sinusoidal to WGS84 projection and mosaicked based on nearest neighbor resample routine using Arcmap 10.0 software. By combining data for the entire Hainan Island area administrative boundary, we acquired an annual maximum NDVI data for 15 year, from 2001 to 2015.

We obtained monthly precipitation, average temperature from the National Meteorological Center of China (2001-2015) and conducted Kriging interpolation on the data obtained from seven meteorological stations in Hainan. By applying a Kriging interpolation to the 2 climate indices with Arcmap 10.0 software, we obtained 30 grid maps of climate index throughout Hainan Island from 2001 to 2015. The projection method and spatial resolution of these data were kept consistent with the NDVI data. The afforested areas and the land used for urban construction areas were acquired from the Hainan statistical yearbook between 2001 and 2015.

2.3. Methods

2.3.1. Trend analysis. The variation trend of residual error or predicted NDVI was calculated using the slope of variation trend using the least squares methods. The significance of the trend was further examined using F test. The formula of trend analysis is as follows[16]:

$$\theta_{\text{slope}} = \frac{n \times \sum_{i=1}^n x_i V_i - \sum_{i=1}^n x_i \sum_{i=1}^n V_i}{n \times \sum_{i=1}^n x_i^2 - (\sum_{i=1}^n x_i)^2} \quad (1)$$

Where θ_{slope} is the slope of the variation trend; i is the time series from 1 to 15 in the study period, n is the year range corresponding to the residual error or predicted NDVI, x_i is the sequence number of the year, and V_i is the residual error value or predicted NDVI values at the time i . If $\theta_{\text{slope}} > 0$, that

indicates a decline in residual error or predicted NDVI, similarly if $\theta_{\text{slope}} < 0$, that indicates a increase in residual error or predicted NDVI.

2.3.2. Multiple linear regression model of NDVI and climate factors. We established a two element linear regression model of each pixel based on annual maximum NDVI values from 2001 to 2015 and average temperature and total precipitation in the corresponding year[17]:

$$\mathbf{V} = (\mathbf{a} \times \mathbf{P}) + (\mathbf{b} \times \mathbf{T}) + \mathbf{c} \quad (2)$$

Where V represents the predicted annual maximum NDVI values, P and T are average temperature and total precipitation, a is the regression coefficient for average temperature, b is the regression coefficient for total precipitation, and c is a regression constant.

Finally, we can calculate the predicted value based on the above multiple linear regression model for every pixel on Hainan Island during 2001-2015.

2.3.3. Residual trend method. Residual trend method was proposed by Evans and Geerken[18-19]. We calculated the year-by-year and pixel-by-pixel predicted annual NDVI values from 2001 to 2015 with the multiple linear regression model. The influence of climate variable on NDVI can be represented by the predicted annual NDVI values. Then, we calculated the residual error between the actual values and predicted values. This method can effectively distinguish between the impacts of climate variation and human activities on vegetation variation. The equation is as follows[20]:

$$\mathbf{V}' = \mathbf{V}_a - \mathbf{V}_p \quad (3)$$

Where V' is the residual error value, V_a is the actual value from MODIS NDVI, and V_p is the predicted annual NDVI values. The change in obtained NDVI residuals was analyzed for the time series from 1998 to 2011. If the result was positive, human activities had improved NDVI in the selected pixel; if the result was negative, NDVI deteriorated under the influence of human activities.

3. Result and analysis

3.1. Vegetation spatial variation under the influence of the climatic factors

We calculated the pixel-by-pixel predicted annual NDVI from 2001 to 2015 using the regression model of climatic factors (annual average temperature and total precipitation) and annual maximum NDVI values. Then, we calculated the variation trend of the predicted value during 2001-2015 as shown in figure 2a. The predicted vegetation across Hainan Island increased, with a linear growth rate of 0.0025/10y ($p < 0.05$). Although the vegetation on Hainan Island had improved on the whole, there were still differences in spatial distribution. The areas where vegetation increased ($\theta_{\text{slope}} > 0$) accounted for 52.28%, while the areas where vegetation ($\theta_{\text{slope}} < 0$) decreased accounted for 47.72%, that indicated the climatic factors were benefit to vegetation for more than one half of regions. As for the former part, significant increased and significant decreased areas account for 9.78% and 6.1%, of the entire study areas (figure 2b). The areas of increased vegetation were located in the center of Chengmai and Baisha, the Southeast of Haikou and Dongfang, and most of Wenchang, Qiongzong and Tunchang, among them the significant increased areas primarily distributed in Lingshui and Wuzhishan. The areas of decreased vegetation were mainly distributed in handover area of Danzhou and Lin'gao, the northeastern Sanya, the northern Wanning, the center of Ledong, the center of Dongfang, most of Haikou and Qionghai, and the eastern Lingshui, among them the significant decreased areas primarily distributed in Sanya and Baoting.

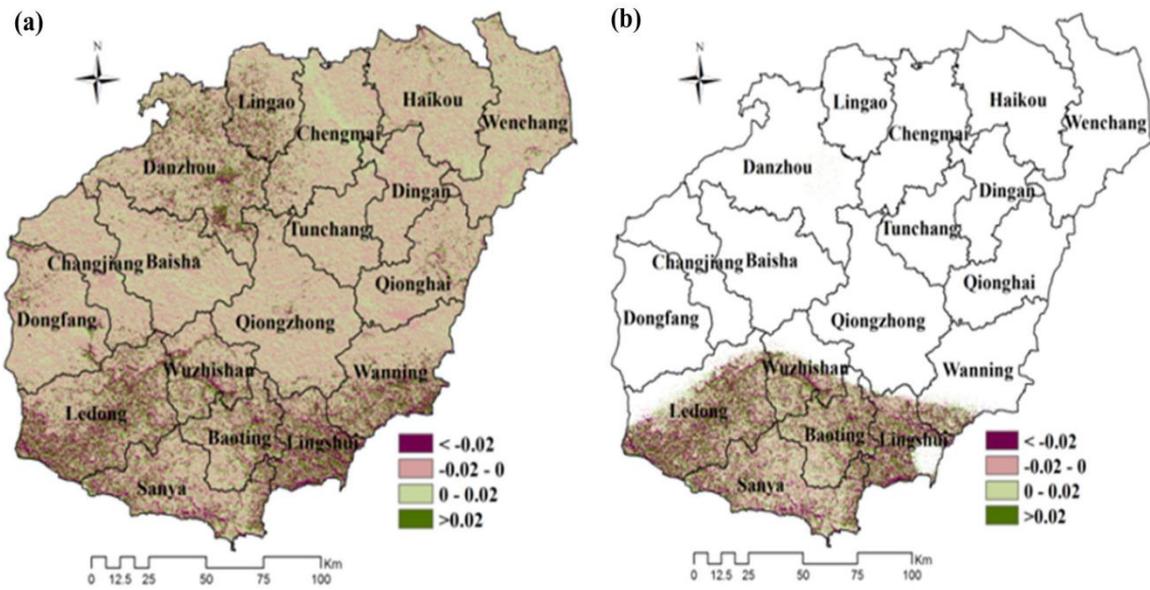


Figure 2.Trends of predicted NDVI variation on Hainan Island from 2001-2015(a),significance test of predicted NDVI variation on Hainan Island from 2001-2015 ($p < 0.05$) (b).

3.2. *Vegetation spatial variation under the influence of the human activities*

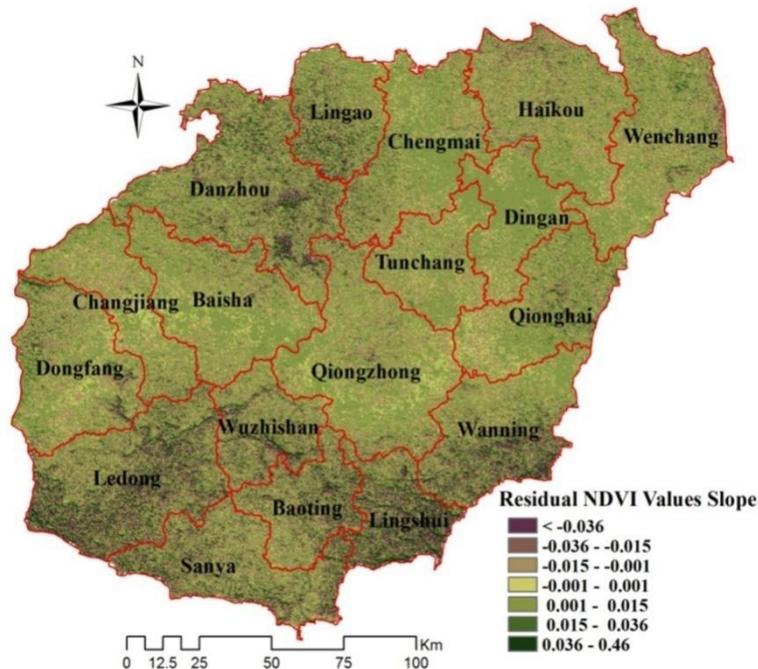


Figure 3.Trends of residual NDVI variation on Hainan Island from 2001-2015.

The vegetation change under the impact of human activities was analyzed using the residual analysis. The residual NDVI values across the region significantly increased, with a growth rate of 0.023/10y, which was significantly more than that of predicted NDVI values though multiple linear regression model. To assess levels of residual NDVI values variation, we categorized slope value into seven standard levels (table 1). These levels were as follows: serious decrease, moderate decrease, light decrease, unchanged, mild increase, moderate increase, and strong increase. From 2001 to 2015, a regressive trend was evident in 20.2% of the region (figure 3).The percentage of increasing areas was

35.95%, and the percentage of basically uncharged areas was 43.86%. In terms of the spatial distribution of residual NDVI values, areas of increased vegetation were also mainly distribution in the northeastern Danzhou, eastern Lingao, the center of Wuzhishan and Ding'an, and southwestern, where the human activities were agriculture planting. For example, it had paid great attention to developing rubber planting in Danzhou, and Lingshui is the production base of winter counter-season vegetation. Areas of vegetation degradation were mainly located in the coastal cities including southeastern Danzhou, the center of Ledong, Lingshui, Sanyan and northern Haikou. In addition, vegetation changes also showed a decreasing trend in Wanning, Wenchang and Baoting, as observed in figure 3.

Table 1. Residual NDVI changes on Hainan Island during 2001-2015.

Classical Standard	Range	percentage	Cumulative percentage
serious decrease	≤ -0.036	2.52%	2.51%
moderate decrease,	-0.036 – -0.015	6.09%	8.6%
light decrease	-0.015 – -0.005	11.59%	20.2%
unchange	-0.005 – 0.005	43.86%	64.05%
mild increase	0.005 – 0.015	23.81%	87.86%
moderate increase,	0.015 – 0.036	8.98%	96.84%
strong increase	≥ 0.036	3.16%	100%

4. Discussion

Though the above analysis, it can be concluded that human activities played a positive role in vegetation growth over the past 15 years. The government has been implementing the Grain-for-Green (GFG) program on Hainan Island since 2002, which laid the foundation for rapid increase of NDVI. Over the past 15 years, afforested areas covered an area of $40.32 \times 10^2 \text{ km}^2$. The coverage of the GFG program peaked in 2003, with afforested areas of $7.52 \times 10^2 \text{ km}^2$ (figure 4a). In 2007, the focus of GFG shifted from expanding forest areas and gradually restoring the ecology to consolidating established gains and improving the program's policies. Although the afforested areas decreased, but improved vegetation quality has been promoted via plots established for afforesting, replanting, and restoring vegetation, as well as through continued cultivation of the existing vegetation, thus providing a continual increase in vegetation coverage, with the forest coverage rate increasing, from 51.2% in 2001 to 62% in 2015. The decreased regions may be caused by rapid urbanization, land reclamation, by means of field surveys and examining literatures. The decreased areas were mainly distribution in the cities where the areas of land used for urban construction were high, as observed in figure 3 and figure 4b. For example, the development of Hainan Island into an international tourist destination was part of a national strategy for development initiated in the early 2010s, then the area of land used for urban construction increased 94.04 km^2 in Sanya from 2011 to 2015, with a growth rate of 178.44%.

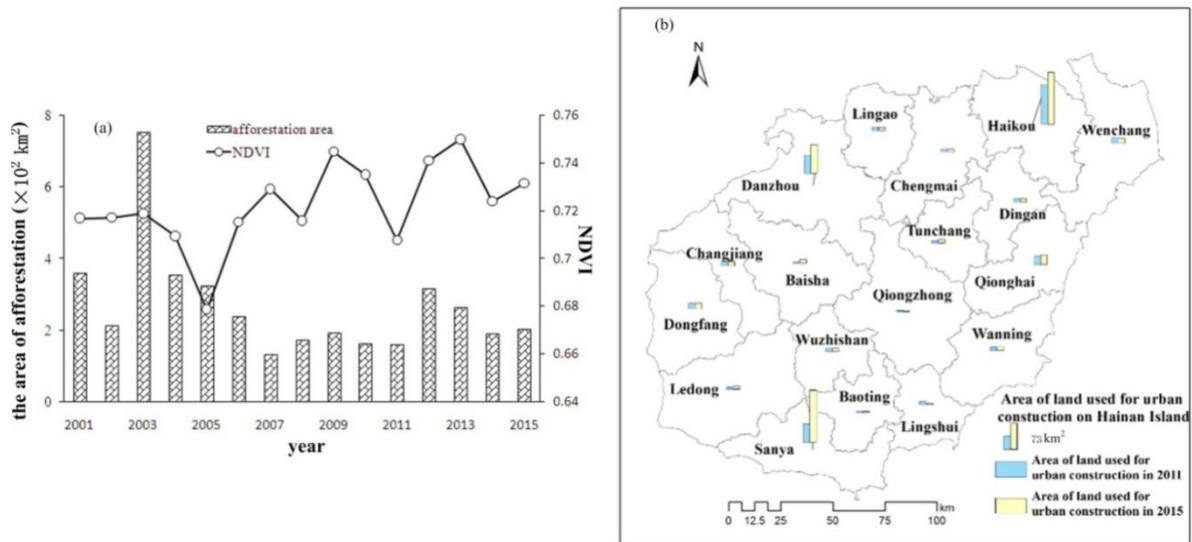


Figure 4. Annual afforested areas and NDVI values on Hainan Island (a), the area of land used for urban construction on Hainan Island in 2001 and 2015 (b).

The influence of climate was analyzed through a regression model of NDVI and temperature and precipitation in this research, but the two indicators adopted are only a part influential factors and do not fully reflect the impact of climate change in vegetation variation. Therefore, a more accurate model to reflect the relation between climate and vegetation variable is needed. Moreover, we only showed that in which regions human activities promote vegetation growth and in which regions human activities induced vegetation growth. What types of human activities promoted or inhibited the vegetation growth? How to quantitatively assess the relative role of climate and human activities on Hainan Island? In order to understand these problems, a wide range of investigation and research should be carried out in the future.

5. Conclusions

The Research revealed the impact of human activities in the process of vegetation variation on Hainan Island using the residual trend method. In this paper, MODIS13Q1 NDVI data were used to analyze the vegetation variation and the influence of human activities on vegetation variation during 2001-2015. The main conclusions are as follows:

- 1) The predicted vegetation on Hainan Island showed an increasing trend with a linear growth rate of 0.0025/10y over the past 15 years. The areas where vegetation increased accounted for 52.28%, while the areas where vegetation decreased accounted for 47.72%.
- 2) The residual NDVI values across the region significantly increased, with a growth rate of 0.023/10y. In terms of the spatial distribution of residual NDVI values, vegetation increased across 35.95% of Hainan Island, while it decreased in 20.2% of the area as a result of human activities.
- 3) On the whole, human activities had played a positive role in the vegetation increase on Hainan Island. The areas of increased vegetation influenced by human activities were mainly distribution in where the human activities were agriculture planting. For example, it has paid great attention to developing rubber planting in Danzhou, and Lingshui is the production base of winter counter-season vegetation. The decreased regions may be caused by rapid urbanization, land reclamation.

Acknowledgment

The study supported by funding from the Natural Science Foundation of Hainan (417238), research and public service industry (agricultural) (201403075), and the basal research fund of Chinese Academy of Tropical Agricultural Sciences (1630072016008). The authors thank NASA and the National Meteorological center of China for supplying the satellite images and climatic data.

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